APPENDIX B
HUMAN HEALTH EFFECTS FROM NORMAL OPERATIONS

B.1 INTRODUCTION

This appendix provides a brief general discussion on radiation and its health effects. It also describes the methods and assumptions used for estimating the potential impacts and risks to individuals and the general public from exposure to releases of radioactivity during normal MPF operations.

B.2 RADIOLOGICAL IMPACTS ON HUMAN HEALTH

Radiation exposure and its consequences are topics of interest to the general public. For this reason, this Environmental Impact Statement (EIS) places emphasis on the consequences of exposure to radiation, provides the reader with information on the nature of radiation, and explains the basic concepts used in the evaluation of radiation health effects.

B.2.1 Nature of Radiation and Its Effects on Humans

What Is Radiation?

Radiation is energy transferred in the form of particles or waves. Globally, human beings are exposed constantly to radiation from space and the Earth's rocks and soil. This radiation contributes to the natural background radiation that always surrounds us. Man-made sources of radiation also exist, including medical and dental x-rays, household smoke detectors, and materials released from nuclear and coal-fired power plants.

All matter in the universe is composed of atoms. Radiation comes from the activity of tiny particles within an atom. An atom consists of a positively charged nucleus (central part of an atom) with a number of negatively charged electron particles in various orbits around the nucleus. There are two types of particles in the nucleus: neutrons that are electrically neutral and protons that are positively charged. Atoms of different types are known as elements. There are more than 100 natural and man-made elements. An element has equal numbers of electrons and protons. When atoms of an element differ in their number of neutrons, they are called isotopes of that element. All elements have three or more isotopes, some or all of which could be unstable (i.e., decay with time).

Unstable isotopes undergo spontaneous change, known as radioactive disintegration or radioactive decay. The process of continuously undergoing spontaneous disintegration makes the material radioactive. The radioactivity of a material decreases with time. The time it takes a material to lose half of its original radioactivity is its half-life. An isotope's half-life is a measure of its decay rate. For example, an isotope with a half-life of 8 days will lose one-half of its radioactivity in that amount of time. In 8 more days, one-half of the remaining radioactivity will be lost, and so on. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to millions of years.

As unstable isotopes change into more stable forms, they often emit electrically charged particles. These particles may be either an alpha particle (a helium nucleus) or a beta particle (an electron), with various levels of kinetic energy. Sometimes these particles are emitted in conjunction with gamma rays. The alpha and beta particles are frequently referred to as ionizing radiation. Ionizing radiation refers to the fact that the charged particle energy can ionize, or electrically charge, an atom by stripping off one of its electrons. Gamma rays, even though they do not carry an electric charge as they pass through an element, can ionize its atoms by causing it to eject electrons. Thus, they cause ionization indirectly. Ionizing radiation can cause a change in the chemical composition of many things, including living tissue (organs), which can affect the way they function.

When a radioactive isotope of an element emits a particle, it changes to an entirely different element, one that may or may not be radioactive. Eventually a stable element is formed. This transformation, which may take several steps, is known as a decay chain. For example, radium, which is a member of the radioactive decay chain of uranium, has a half-life of 1,622 years. It emits an alpha particle and becomes radon, a radioactive gas with a half-life of only 3.8 days. Radon decays first to polonium, then through a series of further decay steps to bismuth, and ultimately to a stable isotope of lead. Meanwhile, the decay products will build up and eventually die away as time progresses.

The characteristics of various forms of ionizing radiation are briefly described below.

Radiation Type	Typical Travel Distance in Air	Barrier
Alpha (a)	Few centimeters	Sheet of paper or skin's surface
Beta (ß)	Few meters	Thin sheet of aluminum foil or glass
Gamma (?)	Very large	Thick wall of concrete, lead, or steel
Neutrons (n)	Very large	Water, paraffin, graphite

Alpha (a)—Alpha particles are the heaviest type of ionizing radiation. They can travel only a few centimeters in air. Alpha particles lose their energy almost as soon as they collide with anything. They can be stopped easily by a sheet of paper or by the skin's surface.

Beta (ß)—Beta particles are much (7,330 times) lighter than alpha particles. They can travel a longer distance than alpha particles in the air. A high-energy beta particle can travel a few meters in the air. Beta particles can pass through a sheet of paper, but may be stopped by a thin sheet of aluminum foil or glass.

Gamma (?)—Gamma rays (and x-rays), unlike alpha or beta particles, are waves of pure energy. Gamma rays travel at the speed of light. Gamma radiation is very penetrating and requires a thick wall of concrete, lead, or steel to stop it.

Neutrons (n)—Neutrons are particles that contribute to radiation exposure both directly and indirectly. The most prolific source of neutrons is a nuclear reactor. Indirect radiation exposure occurs when gamma rays and alpha particles are emitted following neutron capture in matter. A neutron has about one-quarter the weight of an alpha particle. It will travel in the air until it is absorbed in another element.

Units of Radiation Measure

During the early days of radiological experience, there was no precise unit of radiation measure. Therefore, a variety of units were used to measure radiation. These units were used to determine the amount, type, and intensity of radiation. Just as heat can be measured in terms of its intensity or effects using units of calories or degrees, quantities of radioactive material can be measured in units of curies, and its effects can be measured in units of radiation absorbed dose (rad), or dose equivalent (rem). The following summarizes those units.

Curie—The curie is the basic unit used to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the same rate of decay of 1 gram of radium. A curie is also a quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second. The unit was named for Marie and Pierre Curie, who discovered radium in 1898.

Rad—The rad is the unit of measurement for the physical absorption of radiation. The total energy absorbed per unit quantity of tissue is referred to as absorbed dose (or simply dose). As sunlight heats pavement by giving up an amount of energy to it, radiation similarly gives up energy to objects in its path. One rad is equal to the amount of radiation that leads to the deposition of 0.01 joule of energy per kilogram (kg) of absorbing material.

Radiation Units and Conversions to International System of Units
1 curie = 3.7×10^{10} disintegrations per second
= 3.7×10^{10} becquerels
1 becquerel = 1 disintegration per second
1 rad = 0.01 gray
1 rem= 0.01 sievert
1 gray = 1 joule per kilogram

Rem—A rem is a measurement of the dose equivalent from radiation based on its biological effects. The rem is used in measuring the effects of radiation on the body as degrees centigrade are used in measuring the effects of sunlight heating pavement. Thus, 1 rem of one type of radiation is presumed to have the same biological effects as 1 rem of any other kind of radiation. This allows comparison of the biological effects of radionuclides that emit different types of radiation. One rem is equal to 1,000 millirem (mrem).

In the International System of Units, the unit of radioactivity (source intensity) is becquerel, the unit of absorbed dose is gray, and the unit of dose equivalent (biological effect) is the sievert.

An individual may be exposed to ionizing radiation externally (from a radioactive source outside the body) or internally (from ingesting or inhaling radioactive material). The external dose is different from the internal dose because an external dose is delivered only during the actual time of exposure to the external radiation source, while an internal dose continues to be delivered as long as the radioactive source is in the body. The dose from internal exposure is calculated over 50 years following the initial exposure. Dose delivered by external radiation and by internally deposited radionuclides (internal dose) is presumed to be biologically equivalent. In practice, for long-lived radionuclides, internal doses are delivered slowly over 50 years and the biological harm is likely to be less.

Sources of Radiation

The average American receives a total of approximately 360 millirem per year (mrem/yr) from all sources of radiation, both natural and manmade, of which approximately 300 mrem/yr are from natural sources. The sources of radiation can be divided into six different categories: (1) cosmic radiation, (2) terrestrial radiation, (3) internal radiation, (4) consumer products, (5) medical diagnosis and therapy, and (6) other sources (National Council on Radiation Protection and Measurements [NCRP] 1987). These categories are discussed in the following paragraphs.

Cosmic Radiation—Cosmic radiation is ionizing radiation resulting from energetic charged particles from space continuously hitting the Earth's atmosphere. These particles and the secondary particles and photons they create comprise cosmic radiation. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with the altitude above sea level. The average dose to people in the United States from this source is approximately 27 mrem/yr.

External Terrestrial Radiation—External terrestrial radiation is the radiation emitted from the radioactive materials in the Earth's rocks and soils. The average dose from external terrestrial radiation is approximately 28 mrem/yr.

Internal Radiation—Internal radiation results from the human body metabolizing natural radioactive material that has entered the body by inhalation or ingestion. Natural radionuclides in the body include isotopes of uranium, thorium, radium, radon, polonium, bismuth, potassium, rubidium, and carbon. The major contributor to the annual dose equivalent for internal radioactivity is the short-lived decay products of radon, which contribute approximately 200 mrem/yr. The average dose from other internal radionuclides is approximately 39 mrem/yr.

Consumer Products—Consumer products also contain sources of ionizing radiation. In some products, such as smoke detectors and airport x-ray machines, the radiation source is essential to the product's operation. In other products, such as televisions and tobacco, the radiation occurs as the products function. The average dose from consumer products is approximately 10 mrem/yr.

Medical Diagnosis and Therapy—Radiation is an important diagnostic medical tool and cancer treatment. Diagnostic x-rays result in an average exposure of 39 mrem/yr. Nuclear medical procedures result in an average exposure of 14 mrem/yr.

Other Sources—There are a few additional sources of radiation that contribute minor doses to individuals in the United States. The dose from nuclear fuel cycle facilities (e.g., uranium mines, mills, and fuel processing plants) and nuclear power plants has been estimated to be less than 1 mrem/yr. Radioactive fallout from atmospheric atomic bomb tests, emissions from certain mineral extraction facilities, and transportation of radioactive materials contribute less than 1 mrem/yr to the average dose to an individual. Air travel contributes approximately 1 mrem/yr to the average dose.

Exposure Pathways

As stated earlier, an individual may be exposed to ionizing radiation both externally and internally. The different ways that could result in radiation exposure to an individual are called exposure pathways. Each type of exposure is discussed separately in the following paragraphs.

External Exposure—External exposure can result from several different pathways, all having in common the fact that the source of radiation causing the exposure is external to the body. These pathways include exposure to a cloud of radioactive material passing over the receptor (i.e., an individual member of the public), standing on ground that is contaminated with radioactivity, and swimming or boating in contaminated water. If the receptor departs from the source of radiation exposure, the dose rate will be reduced. It is assumed that external exposure occurs uniformly during the year. The appropriate dose measure is called the effective dose equivalent.

Internal Exposure—Internal exposure results from a radiation source entering the human body through either inhalation of contaminated air or ingestion of contaminated food or water. In contrast to external exposure, once a radiation source enters the body, it remains there for a period of time that varies depending on decay and biological half-life. The absorbed dose to each organ of the body is calculated for a period of 50 years following the intake. The calculated absorbed dose is called the committed dose equivalent. Various organs have different susceptibilities to harm from radiation. The quantity that takes these different susceptibilities into account is called the committed effective dose equivalent, and it provides a broad indicator of the risk to the health of an individual from radiation. The committed effective dose equivalent is a weighted sum of the committed dose equivalent in each major organ or tissue. The concept of committed effective dose equivalent applies only to internal pathways.

Radiation Protection Guides

Various organizations have issued radiation protection guides. The responsibilities of the main radiation safety organizations, particularly those that affect policies in the United States, are summarized below.

International Commission on Radiological Protection (ICRP)—This Commission has the responsibility for providing guidance in matters of radiation safety. The operating policy of this organization is to prepare recommendations to deal with basic principles of radiation protection and to leave to the various national protection committees the responsibility of introducing the detailed technical regulations, recommendations, or codes of practice best suited to the needs of their countries.

National Council on Radiation Protection and Measurements—In the United States, this Council is the national organization that has the responsibility for adapting and providing detailed technical guidelines for implementing the ICRP recommendations. The Council consists of technical experts who are specialists in radiation protection and scientists who are experts in disciplines that form the basis for radiation protection.

National Research Council/National Academy of Sciences—The National Research Council is an organization within the National Academy of Sciences that associates the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the Federal government.

Environmental Protection Agency (EPA)—The EPA has published a series of documents, *Radiation Protection Guidance to Federal Agencies*. This guidance is used as a regulatory benchmark by a number of Federal agencies, including the U.S. Department of Energy (DOE), in the realm of limiting public and occupational work force exposures to the greatest extent possible.

Limits of Radiation Exposure

Limits of exposure to members of the public and radiation workers are derived from ICRP recommendations. The EPA uses the NCRP and the ICRP recommendations and sets specific annual exposure limits (usually less than those specified by the Commission) in *Radiation Protection Guidance to Federal Agencies* documents. Each regulatory organization then establishes its own set of radiation standards. The various exposure limits set by DOE and the EPA for radiation workers and members of the public are given in Table B.2.1–1.

Table B.2.1–1. Exposure Limits for Members of the Public and Radiation Workers

Guidance Criteria (Organization)	Public Exposure Limits at the Site Boundary	Worker Exposure Limits
10 CFR 835 (DOE)	—	5,000 mrem/yr [a]
10 CFR 835.1002 (DOE)	—	1,000 mrem/yr [b]
DOE Order 5400.5 (DOE) [c]	10 mrem/yr (all air pathways) 4 mrem/yr (drinking water pathway) 100 mrem/yr (all pathways)	—
40 CFR 61 (EPA)	10 mrem/yr (all air pathways)	—
40 CFR 141 (EPA)	4 mrem/yr (drinking water pathways)	—

[a] Although this is a limit (or level) which is enforced by DOE, worker doses must still adhere to as low as is reasonably achievable principles. Refer to footnote b.
[b] This is a control level. It was established by DOE to assist in effecting its goal to maintain radiological doses as low as is reasonably achievable. DOE recommends that facilities adopt a more limiting 500 mrem/yr Administrative Control Level (DOE 1999e). Reasonable attempts have to be made by the site to maintain individual worker doses below these levels.
[c] Derived from 40 CFR 61, 40 CFR 141, and 10 CFR 20.

B.2.2 Health Effects

Radiation exposure and its consequences are topics of interest to the general public. To provide the background for discussions of impacts, this section explains the basic concepts used in the evaluation of radiation effects.

Radiation can cause a variety of damaging health effects in people. The most significant effects are induced cancer fatalities. These effects are referred to as "latent" cancer fatalities because the cancer may take many years to develop. In the discussions that follow, all fatal cancers are considered latent; therefore, the term "latent" is not used.

The National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR) has prepared a series of reports to advise the U.S. Government on the health consequences of radiation exposures. *Health Effects of Exposure to Low Levels of Ionizing*

Radiation, BEIR V (NRC 1990), provides the most current estimates for excess mortality from leukemia and other cancers that are expected to result from exposure to ionizing radiation. BEIR V provides estimates that are consistently higher than those in its predecessor, BEIR III. This increase is attributed to several factors, including the use of a linear dose response model for cancers other than leukemia, revised dosimetry for the Japanese atomic bomb survivors, and additional followup studies of the atomic bomb survivors and associated others. BEIR III employs constant, relative, and absolute risk models, with separate coefficients for each of several sex and age-at-exposure groups. BEIR V develops models in which the excess relative risk is expressed as a function of age at exposure, time after exposure, and sex for each of several cancer categories. The BEIR III models were based on the assumption that absolute risks are comparable between the atomic bomb survivors and the U.S. population. BEIR V models were based on the assumption that the relative risks are comparable. For a disease such as lung cancer, where baseline risks in the United States are much larger than those in Japan, the BEIR V approach leads to larger risk estimates than the BEIR III approach.

The models and risk coefficients in BEIR V were derived through analyses of relevant epidemiologic data that included the Japanese atomic bomb survivors, ankylosis spondylitis patients, Canadian and Massachusetts fluoroscopy (breast cancer) patients, New York postpartummastitis (breast cancer) patients, Israeli tinea capitis (thyroid cancer) patients, and Rochester thymus (thyroid cancer) patients. Models for leukemia, respiratory cancer, digestive cancer, and other cancers used only the atomic bomb survivor data, although results of analyses of the ankylosis spondylitis patients were considered. Atomic bomb survivor analyses were based on revised dosimetry, with an assumed relative biological effectiveness of 20 for neutrons, and were restricted to doses less than 400 rads. Estimates of risks of fatal cancers, other than leukemia, were obtained by totaling the estimates for breast cancer, respiratory cancer, digestive cancer, and other cancers.

The NCRP (NCRP 1993), based on the radiation risk estimates provided in BEIR V and the ICRP Publication 60 recommendations (ICRP 1991), has estimated the total detriment resulting from low dose[1] or low dose rate exposure to ionizing radiation to be 5.6×10^{-4} per rem for the working population and 7.3×10^{-4} per rem for the general population. The total detriment includes fatal and nonfatal cancer, which is severe hereditary (genetic) effects. The major contribution to the total detriment is from fatal cancer, which is estimated to be 4×10^{-4} and 5×10^{-4} per rem for radiation workers and the general population, respectively. The breakdowns of the risk estimators for both workers and the general population are given in Table B.2.2–1. Nonfatal cancers and genetic effects are less probable consequences of radiation exposure. To simplify the presentation of the impacts, estimated effects of radiation are calculated only in terms of cancer fatalities. For higher doses to an individual (20 rem or more), as could be associated with postulated accidents, the risk estimators given in Table B.2.2–1 are doubled.

[1]Low dose is defined as the dose level where deoxyribonucleic acid (DNA) repair can occur in a few hours after irradiation induced damage. Currently, a dose level of about 0.2 grays (20 rad), or a dose rate of 0.1 milligrays (0.01 rad) per minute is considered low enough to allow the DNA to repair itself in a short period (EPA 1999a).

The numerical estimates of fatal cancers presented in this EIS were obtained using a linear extrapolation from the nominal risk estimated for lifetime total cancer mortality that results from a dose of 0.1 gray (10 rad). Other methods of extrapolation to the low-dose region could yield higher or lower numerical estimates of fatal cancers. Studies of human populations exposed to low doses are inadequate to demonstrate the actual level of risk. There is scientific uncertainty about cancer risk in the low-dose region below the range of epidemiologic observation, and the possibility of no risk cannot be excluded (DOE 1996c).

Table B.2.2–1. Nominal Health Risk Estimators Associated with Exposure to 1 Rem of Ionizing Radiation

Exposed Individual	Fatal Cancer [a, c]	Nonfatal Cancer [b]	Genetic Disorders [b]	Total
Worker	0.0004	0.00008	0.00008	0.0005
Public	0.0005	0.0001	0.00013	0.00073

[a] For fatal cancer, the health effect coefficient is the same as the probability coefficient. When applied to an individual, the units are the lifetime probability of a cancer fatality per rem of radiation dose. When applied to a population of individuals, the units are the excess number of fatal cancers per person-rem of radiation dose.
[b] In determining a means of assessing health effects from radiation exposure, the ICRP has developed a weighting method for nonfatal cancers and genetic effects.
[c] For high individual exposures (greater than or equal to 20 rem), the health factors are multiplied by a factor of 2.
Source: NCRP 1993.

Health Effect Risk Estimators Used in This EIS

Health impacts from radiation exposure, whether from external or internal sources, generally are identified as "somatic" (i.e., affecting the exposed individual) or "genetic" (i.e., affecting descendants of the exposed individual). Radiation is more likely to produce somatic effects than genetic effects. The somatic risks of most importance are induced cancers. Except for leukemia, which can have an induction period (time between exposure to carcinogen and cancer diagnosis) of as little as 2-7 years, most cancers have an induction period of more than 20 years.

For a uniform irradiation of the body, the incidence of cancer varies among organs and tissues; the thyroid and skin demonstrate a greater sensitivity than other organs. Such cancers, however, also produce relatively low mortality rates because they are relatively amenable to medical treatment. Because fatal cancer is the most probable serious effect of environmental and occupational radiation exposures, estimates of cancer fatalities rather than cancer incidence are presented in this EIS. The numbers of fatal cancers can be used to compare the risks among the various alternatives.

Based on the preceding discussion and the values presented in Table B.2.2–1, the number of fatal cancers to the general public during normal operations and for postulated accidents in which individual doses are less than 20 rem are calculated using a health risk estimator of 5×10^{-4} per person-rem. For workers, a risk estimator of 4×10^{-4} excess fatal cancers per person-rem is used. (The risk estimators are lifetime probabilities that an individual would develop a fatal cancer per rem of radiation received.) The lower value for workers reflects the absence of children (who are more radiosensitive than adults) in the workforce. The risk estimators associated with nonfatal cancer and genetic disorders among the public are 20 and 26 percent, respectively, of the fatal cancer risk estimator. For workers, these health risk estimators are both 20 percent of the fatal cancer risk estimator. The nonfatal cancer and genetic disorder risk estimators are not used in this EIS.

For individual doses of 20 rem or more, as could be associated with postulated accidents, the risk estimators used to calculate health effects to the general public and to workers are double those given in the previous paragraph, which are associated with doses of less than 20 rem.

The fatal cancer estimators are used to calculate the statistical expectation of the effects of exposing a population to radiation. For example, if 100,000 people were each exposed to one-time radiation dose of 100 mrem (0.1 rem), the collective dose would be 10,000 person-rem. The exposed population would then be expected to experience five additional cancer fatalities from the radiation (10,000 person-rem $\times$ 5 $\times$ 10^{-4} lifetime probability of cancer fatalities per person-rem = 5 cancer fatalities).

Calculations of the number of excess fatal cancers associated with radiation exposure do not always yield whole numbers. These calculations may yield numbers less than 1, especially in environmental impact applications. For example, if a population of 100,000 were exposed to a total dose of only 0.001 rem per person, the collective dose would be 100 person-rem, and the corresponding estimated number of cancer fatalities would be 0.05 (100,000 persons $\times$ 0.001 rem $\times$ 5 $\times$ 10^{-4} cancer fatalities per person-rem = 0.05 cancer fatalities). The 0.05 means that there is one chance in 20 that the exposed population would experience one fatal cancer. In other words, the 0.05 cancer fatalities is the *expected* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. In most groups, no person (0 people) would incur a fatal cancer from the 0.001 rem dose each member would have received. In a small fraction of the groups, one cancer fatality would result; in exceptionally few groups, two or more cancer fatalities would occur. The *average* expected number of deaths over all the groups would be 0.05 cancer fatalities (just as the average of 0, 0, 0, and 1 is 1/4, or 0.25). The most likely outcome is 0 cancer fatalities.

The same concept is applied to estimate the effects of radiation exposure on an individual member of the public. Consider the effects of an individual's exposure to a 360 mrem (0.36 rem) annual dose from all radiation sources. The probability that the individual will develop a fatal cancer from continuous exposure to this radiation over an average life of 72 years (presumed) is 0.013 (1 person $\times$ 0.36 rem per year $\times$ 72 years $\times$ 5 $\times$ 10^{-4} cancer fatality risk per person rem = 0.013). This correlates to one chance in 77 that the individual would develop a fatal cancer.

B.3 HEALTH EFFECTS STUDIES: EPIDEMIOLOGY

Various epidemiologic studies have been conducted at some of the sites evaluated in this EIS because of the concern for potential adverse health effects associated with the manufacture and testing of nuclear weapons. These studies focus on the DOE workforce and residents of communities surrounding DOE sites.

B.3.1 Background

The health effects associated with ionizing radiation exposure were first published about 60 years ago. Studies published in the 1930s first documented cancer among painters who used radium to paint watch dials back in 1910 to 1920. Radiation therapy for disease has been used since the 1930s and studies have shown that the risk of cancer was related to the amounts of radiation received. Nuclear weapons research and manufacture, and consequent exposure to radiation occurred beginning in the late 1930s. Exposure to radionuclides has changed over time with higher levels occurring in the early days of research and production. Numerous epidemiologic studies have been conducted among workers who manufactured and tested nuclear weapons due to the concern with potential adverse health effects. More recently, concerns about radiologic contaminants offsite have resulted in health studies among communities that surround DOE facilities. The following section briefly gives an overview of epidemiology followed by a review of epidemiologic studies of sites evaluated in this Programmatic Environmental Impact Statement (PEIS).

Epidemiology is the study of the distribution and determinants of disease in human populations. The distribution of disease is considered in relation to time, place, and person. Relevant population characteristics should include the age, race, and sex distribution of a population, as well as other characteristics related to health, such as social characteristics (e.g., income and education), occupation, susceptibility to disease, and exposure to specific agents. Determinants of disease include the causes of disease, as well as factors that influence the risk of disease.

B.3.1.1 Study Designs

Ecologic Studies

Ecologic studies compare the frequency of a disease in groups of people in conjunction with simple descriptive studies of geographical information in an attempt to determine how health events among populations vary with levels of exposure. These groups may be identified as the residents of a neighborhood, a city, or a county where demographic information and disease or mortality data are available. Exposure to specific agents may be defined in terms of residential location or proximity to a particular area, such as distance from a waste disposal site. An example of an ecologic study is a comparison of the rate of heart disease among community residents by drinking water quality.

The major disadvantage of ecologic studies is that the measure of exposure is based on the average level of exposure in the community, when what is really of interest is each individual's exposure. Ecologic studies do not take into account other factors such as age and race that may also be related to disease. These types of studies may lead to incorrect conclusions, an “ecologic fallacy.” For the above example, it would be incorrect to assume that the level of water hardness influences the risk of getting heart disease. Despite the obvious problems with ecologic studies, they can be a useful first step in identifying possible associations between the risk of disease and environmental exposures. However, because of their potential for bias they should never be considered more than an initial step in investigation of disease causation.

Cohort Studies

The cohort study design is a type of epidemiologic study frequently used to examine occupational exposures within a defined workforce. A cohort study requires a defined population that can be classified as being exposed or not exposed to an agent of interest, such as radiation or chemicals that influence the probability of occurrence of a given disease. Characterization of the exposure may be qualitative (e.g., high, low, or no exposure) or very quantitative (e.g., radiation measured in Sv, chemicals in parts per million [ppm]). Surrogates for exposure, such as job titles, are frequently used in the absence of quantitative exposure data.

Individuals enumerated in the study population are tracked for a period of time and fatalities recorded. In general, overall rates of death and cause-specific rates of death have been assessed for workers at the EIS sites. Death rates for the exposed worker population are compared with death rates of workers who did not have the exposure (internal comparison), or compared with expected death rates based on the U.S. population or state death rates (external comparison). If the rates of death differ from what is expected, an association is said to exist between the disease and exposure. In cohorts where the exposure has not been characterized, excess mortality can be identified, but these deaths cannot be attributed to a specific exposure, and additional studies may be warranted. More recent studies have looked at other disease endpoints, such as overall and cause-specific cancer incidence (newly diagnosed) rates.

Most cohort studies at EIS sites have been historical cohort studies, that is, the exposure occurred some time in the distant past. These studies rely on past records to document exposure. This type of study can be problematic if exposure records are incomplete or were destroyed. Cohort studies require extremely large populations that have been followed for many (20-30) years. They are generally difficult to conduct and are very expensive. These studies are not well suited to studying diseases that are rare. Cohort studies do, however, provide a direct estimate of the risk of death from a specific disease, and allow an investigator to look at many disease endpoints.

Case-Control Studies

The case-control study design starts with the identification of persons with the disease of interest (case) and a suitable comparison (control) population of persons without the disease. Controls must be persons who are at risk for the disease and are representative of the population that generated the cases. The selection of an appropriate control group is often quite problematic. Cases and controls are then compared with respect to the proportion of individuals exposed to the agent of interest. Case-control studies require fewer persons than cohort studies, and therefore, are usually less costly and less time consuming, but are limited to the study of one disease (or cause of death). These types of studies are well suited for the study of rare diseases and are generally used to examine the relationship between a specific disease and exposure.

B.3.1.2 Definitions

Terms used in epidemiologic studies, including those used in this document, are defined below.

Age, gender, and cigarette smoking are the principal determinants of mortality. *Standardization* is a statistical method used as a control for the effects of age, gender, or other characteristics so that death rates may be compared among different population groups. There are two ways to standardize rates, the indirect or direct methods. In general, the indirect method of standardization is most frequently used.

Indirect Standardization—The disease rates in the reference (comparison) population are multiplied by the number of individuals in the same age and gender groups in the study population to obtain the expected rate of disease for the study population.

Direct Standardization—The disease rates in the study population are multiplied by the number of individuals in the same age and gender group in the reference (comparison) population. This gives the expected rates of disease for the reference population if these rates had prevailed in that group.

Standardized Mortality Ratio—The standardized mortality rate (SMR) is the ratio of the number of deaths observed in the study population to the number of expected deaths. The expected number of deaths is based on a reference (or comparison population). Death rates for the U.S. (or state) population are most frequently used as the comparison to obtain expected rates. An SMR of 1 indicates a similar risk of disease in the study population compared with the reference population. An SMR greater than 1 indicates excess risk of disease in the study population compared with the reference group, and an SMR less than 1 indicates a deficit of disease.

Relative Risk—The ratio of the risk of disease among the exposed population to the risk of disease in the non-exposed population. Relative risks are estimated from cohort studies.

Odds Ratio—The ratio of the odds of disease if exposed, to the odds of disease if not exposed. Under certain conditions, the odds ratio approximates the relative risk. Odds ratios are estimated from case-control studies.

B.3.2 Los Alamos Site

Los Alamos and adjacent counties comprise a unique setting and history. Los Alamos Site, for much of its existence, was a closed community where most of the residents had direct economic ties to the laboratory. Nearly all male residents and some of the female residents are employed at Los Alamos National Laboratory (LANL). Medical care in Los Alamos County had been centralized at the laboratory and a single community hospital. This is a unique, highly educated community situated adjacent to lands populated by Native Americans.

Surrounding Communities

Selected cancer mortality and incidence (newly diagnosed cancer) rates between 1950 and 1969, for 11 selected cancers among white males in Los Alamos County were compared with rates for the State of New Mexico, U.S. rates, and with rates of 5 socioeconomic and occupational control counties and 5 high-education western counties, based on U.S. Bureau of the Census information (ER 1981). The comparisons were made to identify cancer types that were greater than expected while taking into account important factors, such as income and education, associated with cancer patterns. Six cancer types were identified that had rates greater than cancer rates for one or more of the four comparison groups; they are: cancer of the bile ducts and liver, bladder, prostate, brain and nervous system, lympho- and reticulo-sarcoma, and leukemia. Cancer rates of the prostate, bladder, and leukemia were also greater than expected.

Compared with New Mexico white males, Los Alamos County Anglo-white males show nonstatistically significant excesses in cancer incidence from 1969-1974 for the stomach, colon, rectum, pancreas, lung, and bladder (ER 1981). All cancers combined show a 35-percent statistically significant excess. Los Alamos County white females show nonstatistically significant excesses for cancer of the stomach, large intestine, lymphosarcoma and reticulasarcoma, and leukemia. All cancers combined show a statistically significant 40-percent excess.

In 1991, the New Mexico Department of Health initiated epidemiologic studies in response to citizen concerns about an apparent excess of brain tumors among residents of the western area neighborhood of Los Alamos County as a result of historical LANL nuclear operations. The New Mexico Department of Health conducted a descriptive study of brain cancer incidence in Los Alamos County and for 22 other sites (NM DOH 1993). The study showed that during the mid- to late-1980s an excess of approximately 80 percent of brain cancer had occurred in Los Alamos County compared with a New Mexico reference population and national statistics. The excess incidence had disproportionately occurred among persons who were residents of the western area at the time of diagnosis or death; however, there were only three cases, and they were confined to the 2-year time period, 1986-1987. Additional descriptive studies showed that the brain cancer rates for Los Alamos County were within the range of rates observed across New Mexico counties from 1983-1987 and 1988-1991. A review of mortality statistics for benign or unspecified neoplasms of the brain and nervous system showed no deaths from these causes in western area residents during 1984-1990.

Los Alamos County breast cancer incidence rates remained level, but higher than New Mexico rates from 1970-1990. Reproductive and demographic factors associated with the risk of breast cancer were thought to account for the higher rates. A special study was conducted to examine the recent increase in breast cancer since 1988 (DOE 1996c). The New Mexico Tumor Registry concluded that the increase seen between 1988 and 1992 was primarily due to increased detection of early stage disease.

The incidence of ovarian cancer in Los Alamos County women was elevated from the mid-1970s to 1990. From 1986-1990, ovarian cancer incidence in Los Alamos County was roughly twofold higher compared with New Mexico reference population rates. The excess ovarian cancer rate was confined to a census tract corresponding to two neighborhoods and was four- to sixfold higher than that observed in the remaining Los Alamos County census tracts.

The incidence rates for melanoma (cancer of the skin) in Los Alamos County were elevated from 1970-1990, with peak elevations occurring from the mid- to late-1980s. There was approximately a twofold excess risk compared with a New Mexico state reference population. The excess melanoma incidence observed in Los Alamos County was thought to be related to the high ambient solar ultraviolet radiation intensity due to its high altitude.

A fourfold increase in thyroid cancer incidence during the late-1980s was noted in a study by Athas (NM DOH 1996). A case-series records review was initiated to examine data relating to the detection, diagnosis, and known risk factors for thyroid cancer. All cases of thyroid cancer diagnosed among Los Alamos County residents between 1970 and 1995 were identified through the New Mexico Tumor Registry. The incidence rate for thyroid cancer in Los Alamos County was slightly higher than New Mexico rates between 1970 and the mid-1980s. There was a statistically significant fourfold increase during the late-1980s and early 1990s compared with the state, but the rate began to decline in 1994 and 1995.

The higher-than-expected number of thyroid cancer cases could not be explained by changes in diagnosis of thyroid cancer among Los Alamos County residents. Additional analyses suggested that increased medical surveillance and greater access to medical care were responsible for the recent excess in Los Alamos County.

Potential risk factors for thyroid cancer including therapeutic irradiation, genetic susceptibility, occupational radiation exposure, and weight were also examined. However, the investigation did not identify a specific cause for the elevated rate of thyroid cancer in Los Alamos County.

Male Workers

A mortality study of 224 white males with the highest internal depositions of plutonium-239 (10 nanocuries [nCi] or more) at Los Alamos Site were examined by Voelz et al. (DOE 1996c). Followup was through April 1980. SMRs were low for all cause of death (SMR: 0.56, 95 percent; Confidence Interval [CI]: 0.40-0.75), all malignant neoplasms (SMR: 0.54, 95 percent; CI: 0.23-1.06), compared with U.S. white males and lung cancer (SMR: 20, 95 percent; CI: 0-110).

A cohort mortality study by Wiggs et al. examined the causes of death among 15,727 white males hired at LANL between 1943 and 1977 (HP 1994). The purpose of the study was to determine if plutonium deposition and external ionizing radiation were related to worker mortality. After nearly 30 years of followup, the LANL workforce experienced 37 percent fewer deaths from all causes, and 36 percent fewer deaths due to cancer than expected when compared with death rates for the U.S. population.

The researchers identified a subset of 3,775 workers who had been monitored for plutonium exposure; of these, 303 workers were categorized as “exposed” based on a urine bioassay for plutonium; the remainder were non-exposed. One case of rare bone cancer, osteogenic sarcoma, a type of cancer related to plutonium exposure in animal studies, was noted among the plutonium exposed group. The overall mortality and site-specific rates of cancer did not differ significantly between the two groups of workers. A nonstatistically significant increase in lung cancer among the exposed group was noted, but there was no information on cigarette use among the workers.

When researchers examined data for the 10,182 workers who were monitored for exposure to external ionizing radiation (including 245 workers exposed to plutonium) they observed a dose-response relationship for cancers of the brain/central nervous system, cancer of the esophagus, and Hodgkin's disease. When the 225 plutonium-exposed workers were excluded from the analysis, there was a statistically significant dose response between external ionizing radiation and kidney cancer and lymphocytic leukemia.

A special lifetime medical study was conducted on 26 of the workers who have the largest internal depositions of plutonium at LANL. Voelz and Lawrence reported on the 42-year followup of the 26 white males who designed and built the first atomic bomb and were determined to have had a significant deposition of plutonium-239 sometime in 1944 or 1945 based on job assignment, working conditions, and urine levels of plutonium (HP 1991). Their mortality experience was compared to U.S. white males adjusted for age and calendar time. The mortality rates were also compared with rates for a cohort of LANL workers hired at the same time and born between the same years; no significant differences were for all cause mortality and all cancer mortality. One of the seven reported deaths was due to bone sarcoma, the most frequent radiation-induced cancer observed in persons with radium depositions.

Wiggs reported on 6,970 women employed at LANL for at least 6 months from 1943-1979, with deaths determined through 1981 (DOE 1996c). The mortality rates for all causes of death combined and all cancers combined were 24 and 22 percent below the rate for the U.S. population, respectively. Although the overall rates are low, women occupationally exposed to ionizing radiation have elevated rates for cancer of the ovary and of the pancreas relative to those not exposed. An unusual finding was that female radiation workers experienced a statistically significant excess of death from suicide. In a special in-depth study, the suicides were compared to two control groups, deaths from other injuries, and deaths from non-injuries. History of employment as a radiation worker was significantly associated with death from suicide for both comparison groups. No significant associations for duration of employment, plutonium exposure, or martial status were seen (DOE 1996c).

As result of a reported threefold excess of malignant melanoma among laboratory workers at Lawrence Livermore National Laboratory (LLNL) in California and similarities between occupational exposures and prevailing sunshine conditions at LANL and LLNL, an investigation was undertaken to assess the risk of melanoma at LANL (Lancet 1981). Incidence data were obtained from the New Mexico Tumor Registry. No excess risk for melanoma was detected at LANL among 11,308 laboratory workers between 1969 and 1978. Six cases were identified where about 5.7 were expected (Lancet 1982). The rate for the total cohort, Hispanic males and females, non-Hispanic males and females were not significantly different from the corresponding New Mexico rates.

A special in-depth study of 15 cases diagnosed through 1982 did not detect an association between melanoma and exposure to any type of external radiation as measured by film badges, neutron exposures, plutonium body burden based on urine samples, or employment as a chemist or physicist (HP 1983). However, the workers with melanoma were more educated than the comparison group using the college and graduate degree as a measure of education, a finding consistent with other reports of malignant melanoma according to the authors. The numbers in this study are too small to detect any but large excesses.

Memorandum of Understanding

DOE entered into a Memorandum of Understanding with the Department of Health and Human Services to conduct health studies at DOE sites. The National Institute for Occupational Safety and Health is responsible for managing or conducting the worker studies. The following multi-site studies that include LANL are currently underway: a study of mortality among female nuclear weapons workers, a case-control study of multiple myeloma, a leukemia study, and an exposure assessment of hazardous waste/cleanup workers.

B.3.3 Nevada Test Site

Surrounding Communities

Aboveground testing of nuclear weapons at Nevada Test Site (NTS) Test Range Complex in southern Nevada between 1951 and 1963 resulted in the dissemination of radioactive fallout over southeastern Nevada and southwestern Utah through wind dispersion. Several epidemiologic studies have been conducted to investigate possible adverse health effects of low-level radioactive fallout on residents of these states. These studies focused on leukemia and thyroid disease in children downwind of NTS.

A series of ecologic studies showed equivocal results in potentially exposed children. A cross-sectional review of thyroid nodularity among teenage children reported by Weiss et al. found no significant difference in the frequency of nodules among potentially exposed and non-exposed children (DOE 1996c). Exposure was defined in terms of county of residence. Rallison et al. reported no significant difference in any type of thyroid disease between Utah children exposed to fallout radiation in the 1950s and control groups drawn from Utah and Arizona (AJM 1974; JAMA 1975).

To investigate the possible relationship between childhood leukemia and radioactive fallout, Lyon et al. conducted a mortality study of Utah children under 15 years old who died in Utah between 1944 and 1975 (NEJM 1979). Lyon et al. selected this age group because of the reported increased susceptibility of children to the neoplastic effects of radiation and the lack of a comparison group over 14 years of age with suitable low exposures. Lyon et al. obtained death certificates from the Utah vital statistics registrar and based on year of death, categorized decedents into either high (fallout years) or low exposure periods (combined pre-fallout years and post-fallout years). From estimated fallout patterns contained in maps of 26 tests, Lyon et al. categorized 17 southern rural counties as high fallout area and the remaining northern urban counties as low fallout area. Age-specific mortality rates derived for deaths which occurred in the combined low exposure periods were compared with those in the high exposure period. For reasons unknown, leukemia mortality during the low exposure periods in high fallout counties was half that of the United States and Utah. A significant excess of leukemia occurred among children statewide who died during the high fallout period compared to those who died during the low fallout periods (SMR: 1.40, 95 percent; CI: 1.08-1.82, $p<0.01$). This excess was more pronounced among those who resided in the high fallout area (SMR: 2.44, 95 percent; CI: 1.18-5.03). No pattern was found for other childhood cancers in relation to fallout exposure. Actual radiation dosage was not available, and the effects of migration were not determined for this study.

Beck and Krey (Science 1983) reconstructed exposure of Utah residents studied by Lyon et al. (NEJM 1979) to external gamma-radiation from NTS fallout through measurements of residual cesium-137 and plutonium in soil. Beck and Krey found that residents in southwest Utah closest to NTS received the highest exposures, but noted that residents of urban northern areas received a higher mean dose and a significantly greater population dose than did residents of most counties closer to the test site. Northern Utah residents received higher average bone doses than southern Utah residents; therefore, distance from NTS should not be the sole criteria for dividing the state into geographic subgroups for the purpose of conducting epidemiologic studies. Beck and Krey concluded that bone doses to southern Utah residents were too low to account for the excess leukemia deaths identified by Lyon et al. They also determined that bone and whole body doses from NTS fallout were small relative to lifetime doses most Utah residents receive from background radiation, and that it was unlikely that these exposures would have resulted in any observed health effects.

Land et al. (Science 1984) attempted to confirm the association between leukemia and fallout reported by Lyon et al. (NEJM 1979) using cancer mortality data from the National Center for Health Statistics for the period 1950 through 1978. No statistically significant differences in mortality from leukemia or other childhood malignancies between northern and southern Utah were observed. The small observed difference in leukemia mortality between the border and interior counties was opposite in direction to that reported by Lyon et al. Results indicated a downward trend in childhood leukemia mortality over time. Eastern Oregon and the State of Iowa also were selected for comparison with Utah. The leukemia mortality rate for eastern Oregon was higher, and Iowa lower than the rate for Utah. Although both were not statistically significant, Land et al. concluded that these results suggest that the association reported by Lyon et al. merely reflects an unexplained low leukemia rate in southern Utah for the period 1944-1949.

Another study that assessed the development of cancer among individuals potentially exposed to radioactive fallout has been reported by Rallison et al. (HP 1990). This study examined the thyroid neoplasia risk in a cohort of children born between 1947-1954 in two counties near nuclear test sites, one in Utah and one in Nevada. A comparison group of Arizona children presumed to have no fallout exposures was also evaluated. The children (11-18 years of age) were examined between 1965-1968 for thyroid abnormalities and were re-examined in 1985 and 1986. Children living in the nuclear testing (Utah/Nevada) area had a higher rate of thyroid neoplasia than the comparison children (in Arizona), but the differences were not statistically significant. The authors concluded that living near NTS in the 1950s has not resulted in a statistically significant increase in thyroid neoplasms.

A study by Johnson examined cancer incidence in a cohort of Mormon families in southwest Utah near the NTS (JAMA 1984b). The study compared cancer incidence among all Utah Mormons during the period 1967-1975 with cancer incidence among two exposed populations: persons residing in a high fallout area and an exposure effects group residing in a broader area that received less intense exposure from radioactive fallout. Limitations of the study include: the inability to locate 40 percent of the defined population, the lack of verifying the reported diagnosis of cancer, and the inability to interview a comparable control group.

Cancer incidence for both exposed groups was compared with that of all Utah Mormons for two timeframes, 1958-1966 and 1972-1980. Johnson found an apparent increased incidence of leukemia and cancers of the thyroid and bone for residents of the high fallout area for both time periods. Additional analyses suggested that a higher proportion of the cancers among exposed groups were in radiosensitive tissues and the proportional excess increased with time compared with all Utah Mormons. The ratio of radiosensitive cancers to all other cancers from 1958-1966 was 24 percent higher among the high fallout area group and 29.6 percent higher among those in the fallout effects group. For 1972-80, the ratio was 53.3 percent higher in the high fallout area group and 300 percent higher in the fallout effects group.

Machado examined cancer mortality rates of a three-county region in southwestern Utah in comparison to the remainder of Utah (AJE 1987). There was no excess risk of cancer mortality in southwest Utah, with the exception of leukemia, which showed a statistically significant excess for all ages combined, and for children age 0-14. In fact, mortality from all cancer sites combined was lower in southwest Utah than the remainder of the state. The authors noted that their findings, including those for leukemia, were inconsistent with the cancer incidence study conducted by Johnson (JAMA 1984b).

Archer measured soil, milk, and bone strontium-90 levels to identify states with high-, intermediate-, and low-fallout contamination (AEH 1987). He then correlated the deaths from radiogenic and nonradiogenic leukemias with the time periods of aboveground nuclear testing both in the United States and Asia. The results show that leukemia deaths in children were higher in states with high exposure and lower in states with less exposure. He showed that leukemia deaths in children peaked approximately 5.5 years following nuclear testing peaks. The last leukemia peak in the United States occurred from 1968-1969, 5½ years after the last year of a 3-year period of intensive testing in Asia. The increases were seen in the radiogenic leukemias (myeloid and acute leukemias), and not with all other leukemias.

Kerber et al. updated a previously identified cohort of children living in portions of Utah, Nevada, and Arizona to estimate individual radiation doses and determine thyroid disease status through 1985-1986 (JAMA 1993). Of the 4,818 children originally examined between 1965-70, 2,473 were included in the followup exam. Outcomes of interest included thyroid cancers, neoplasms, and nodules based on physical examinations of the thyroid. Exposure of the thyroid to radioiodines was based on radionuclide deposition rates provided by DOE and surveys of milk producers. Children with questionable findings were referred to a panel of endocrinologists for further examination. The authors reported an excess number of thyroid neoplasms (combined benign and malignant) and a positive dose-response trend for neoplasms, both of which were statistically significant. The authors also reported a positive dose-response trend for thyroid nodules, not statistically significant, and a positive dose-response trend for thyroid carcinomas with marginal statistical significance. The authors estimated that an excess of between 1-12 neoplasms (between 0-6 excess malignancies) was probably caused by exposure to radioiodines from the nuclear weapons testing. A letter to the editor criticized Kerber et al. for relying on food histories obtained 22 years after the fact to depict radioiodine intake, and for the untested modeling approach for determining dose to the thyroid (JAMA 1994a). These concerns were addressed by Kerber et al., which acknowledged the uncertainties in the dose estimates, but concluded that their estimates were conservative (JAMA 1994b).

Till et al. estimated doses to the thyroid of 3,545 subjects who were exposed to radioiodine fallout from NTS (HP 1995). The U.S. Public Health Service first examined this cohort for thyroid disease between 1965-1970 and later in 1985-1986. Till et al. assigned individual doses based on age, residence histories, dietary histories, and lifestyle. Individualized dose and uncertainty was combined with the results of clinical examinations to determine the relationship between dose from NTS fallout and thyroid disease incidence.

Workers

Military personnel and civilian employees of the Department of Defense observed and participated in maneuvers at the NTS during atmospheric tests. An excess number of leukemia cases was reported (9 cases, 3.5 expected) among the 3,224 men who participated in military maneuvers in August 1957 at the time of the nuclear test explosion “Smoky” (JAMA 1980). The participants were located and queried on their health status, diseases, or hospitalizations as of December 1981. Various Federal records systems were linked, including clinical files, and next of kin were queried about cause of death for those participants who were deceased. Exposure information was available from film badges records, and the mean gamma dose for the entire cohort was 466.2 mrem. In a later report of the same cohort, the number of incident cases of leukemia had increased to 10 with 4 expected (JAMA 1983). No excess in “total cancers” was observed; however, four cases of polycythemia vera were reported where 0.2 were expected (JAMA 1984a). The excess in leukemia cancer incidence and mortality appear to be limited to the soldiers who participated in "Smoky."

The leukemia excess was not observed in a National Research Council mortality study of soldiers exposed to five series of tests at two sites: Nevada Test Site and the Pacific Proving Ground (DOE 1996c). The National Research Council reported that the number of leukemia cases in "Smoky" was greater, but the increase was considered nonsignificant when analyzed with the data from the other four tests. In 1989, however, it was discovered that the roster of the atomic veterans cohort on which the National Research Council based its 1985 study contained misclassification errors. As a result, this study was reanalyzed. In 1997, the Secretary of the Department of Health and Human Services (DHHS) asked the Institute of Medicine (IOM) and the National Research Council to undertake an independent assessment of the public health and medical implications of the estimated iodine-131 doses received by the American people from atmospheric testing and to advise the Department on steps that might be taken in response. Two committees were appointed to perform the assessment. Their results were published in 1999 in *Exposure of the American People to Iodine-131 from Nevada Nuclear-Bomb Tests: Review of the National Cancer Institute Report and Public Health Implications* (NAP 1999). The report's conclusions include:

- The estimate of the American people's collective dose from iodine-131 is consistent with the committee's analysis and is unlikely to greatly over- or understate the actual levels.

- The levels of detail presented in the report, specifically, county-specific estimates of iodine-131 thyroid doses, are probably too uncertain to be used in estimating individual exposure. For the most part, direct measures of fallout for any particular weapons test were made for only about 100 places nationwide (except near NTS itself). Estimates of county-specific exposures may also have little relevance to specific individuals for whom exposure depends on such critical factors as varying individual consumption of milk and other foods and variations in the source of those foods.

- Individual-specific estimates of past exposure to iodine-131 from the Nevada tests are possible but uncertain, often highly so, because critical data are often not available or of questionable reliability. A small minority of the population—those who were young children at the time of testing and who routinely drank milk from backyard cows or, especially, goats—had a significant exposure to iodine-131.

- Exposure to iodine-131 as a byproduct of nuclear reactions can cause thyroid cancer as shown conclusively by the 1986 nuclear accident in Chernobyl, which resulted in high level exposure for many people. The NCI dose reconstruction model indicates that the level of exposure to iodine-131 was sufficient to cause and continue to cause excess cases of thyroid cancer. Because of uncertainty about the doses and the estimates of cancer risk, the number of excess cases of thyroid cancer is impossible to predict except within a wide range.

- Epidemiological analyses of past thyroid cancer incidence and mortality rates provide little evidence of widespread increases in thyroid cancer risk related to the pattern of exposure to iodine-131 described in the NCI report. They suggest that any increase in the number of thyroid cancer cases is likely to be in the lower part of the ranges estimated by NCI. The epidemiologic analyses are, however, subject to many limitations and uncertainties.

- Given the uncertainties in both the dose reconstruction model and the epidemiological analyses, further epidemiologic studies will be necessary to clarify the extent to which Nevada tests increased the incidence of thyroid cancer. Pending these studies, it is prudent for DHHS to plan its responses as if excess cases of thyroid cancer have occurred.

- The type of thyroid cancer, papillary carcinoma, usually linked to radiation exposure is uncommon and rarely life threatening. Even among those with exposure to iodine-131, few will develop thyroid problems.

As a result of this assessment, the committee suggested that DHHS consider additional research in several areas. These areas include (1) the relative effectiveness of external radiation versus internal radiation in producing thyroid cancer; (2) the relative malignancy of radiation-related versus spontaneous thyroid neoplasms; (3) the role of genetic events in the development of thyroid cancer, in particular, the role of ret/PTC oncogene as it may affect the nature of the dose-response relationship for thyroid cancer; (4) people's perceptions of the benefits and risks of screening for thyroid and other cancers and the factors affecting such perceptions including the way quantitative information is presented; and (5) the effectiveness of existing programs to communicate radiation risks (NAP 1999).

B.3.4 Pantex Site

Surrounding Communities

A June 1994 study by the Texas Cancer Registry, Texas Department of Health, showed significant increases in prostate cancer mortality among Potter County and Randall County males, and leukemia mortality among Carson County males during the period between 1981-1992 (DOE 1996c). There were no statistically significant increases observed in site-specific cancer mortality among females during this period. For cancer incidence during the period between 1986-1992, no statistically significant excesses in males were seen; however, cancer of the prostate was slightly elevated in Potter/Randall County males. Analysis of the four major cell-specific types of leukemia, showed a significant excess in the incidence of chronic lymphocytic leukemia among Potter/Randall County females. This study was conducted in Carson, Potter, and Randall Counties, which are located near the Pantex Plant (Pantex). This study focused only on cancers of the breast, prostate, brain, thyroid, and leukemia, which were of specific concern to citizens in the area. Other radiation-associated cancers, such as bone and lung, were not included in this study. Although prostate cancer and chronic lymphocytic leukemia have not been linked to radiation exposure, further followup to this study was recommended.

Workers

An epidemiologic study of Pantex workers was published by Acquavella (HP 1985). This study compared total and cause-specific mortality for Pantex workers employed between 1951 and December 31, 1978, with expected cause-specific mortalities based on U.S. death rates. Significantly fewer deaths were observed in the workforce than would be expected based on U.S.

death rates for the following causes of death: all cancers, arteriosclerotic heart disease, and digestive diseases. No specific causes of death occurred significantly more frequently than expected. Slightly elevated mortality ratios were observed for brain cancer and leukemia; neither excess was statistically significant. The four deaths from brain cancer all occurred among those who had worked at the plant less than 5 years. The four deaths from leukemia occurred with equal frequency among those who had worked at the plant a short time and those who had worked more than 15 years.

Memorandum of Understanding

A followup of the 1985 mortality study of the Pantex workforce has been performed. The 1985 study of Pantex workers was limited by the small number of deaths and short followup, although the risk of several cancers was elevated. National Institute of Occupational Safety and Health performed an intramural study that updated vital status through 1995. An SMR analysis with examination of dose-response was conducted; however, it was not possible to update exposure information for the cohort (duration of employment was used as a surrogate for dose). A decision to return to the facility to conduct an updated analysis is pending. To date, study results have not been released pending communication to workers. As an operating facility that has not been downsized, Pantex will encounter similar exposures to both current and future workers.

Epidemiologic Surveillance

DOE's Office of Epidemiologic Studies Epidemiologic Surveillance Program was implemented at Pantex in 1993 in order to monitor the health of current workers. This program evaluates the occurrence of illness and injury in the workforce on a continuing basis and issues the results of the ongoing surveillance in annual reports. The program facilitates an ongoing assessment of the health and safety of the site's workforce and helps to identify any emerging health issues in a timely manner. Monthly data collection began on January 1, 1994, and the results of the first complete year of epidemiologic surveillance were presented to workers and other site stakeholder groups in spring 1996. The most recent annual report available for review if for the 2001 calendar year.

Currently operational at a number of DOE sites, including production sites and research and development laboratories, epidemiologic surveillance makes use of routinely collected health data including descriptions of illness resulting in absences lasting 5 or more consecutive workdays, disabilities, and OSHA-recordable injuries and illnesses abstracted from the OSHA 200 log. These health event data, coupled with demographic data about the active workforce at the participating sites, are analyzed to evaluate whether particular occupational groups are at increased risk of disease or injury when compared with other workers at a site. As the program continues and data become available for an extended period of time, trend analysis will become an increasingly important part of the evaluation of worker health. Monitoring for changes in the health of the workforce provides both a baseline determination of the illness and injury experience of workers and a tool for monitoring the effects of changes made to improve the safety and health of workers. Noteworthy changes in the health of the workforce may indicate areas in need of more detailed study or increased health and safety measures to ensure adequate protection for workers.

Epidemiologic surveillance monitors all illnesses and injuries among active workers because it is not always possible to determine which health effects are due to occupational exposures and which are due to other causes. Most illness and injury diagnoses were reported to the occupational medicine clinic by workers who required return-to-work clearances. An absence due to illness or injury may involve more than one diagnosis, and epidemiologic surveillance includes all reported diagnoses. In addition, the OSHA 200 Log provides information on recorded occupational injuries and illnesses whether or not they involve absences. number of days lost. The report organizes illness and injury categories based on a standard reference, the International Classification of Disease, 9th Revision, Clinical Modification (ICD-9-CM). This reference is used to classify health events for statistical purposes.

Cancer rates presented in this report are based on reported absences during the year. A worker may experience several periods of absence from one cancer diagnosis due to medical complications or treatment regimens. The likelihood that an individual in the United States develops cancer increases with age. Pantex data tend to reflect this observation among men. Nine men reported 11 absences due to cancer. Four men reported skin cancer, three reported prostate cancer, and one reported thyroid cancer. One man reported cancer of the pancreas that spread to the liver. Among the seven women reporting cancer, only two were over 50 years old. Thirteen absences for cancer were reported. Four women had only one absence, and three women accounted for nine absences. Six women had cancer of only one type: larynx, thyroid, colon, cervix, breast, and Hodgkin's lymphoma. The other woman had malignant melanoma that spread to the lymph nodes. The women with cancer of the colon and Hodgkin's lymphoma reported these same cancers in previous years. None of the other workers who reported cancer in 2001 had reported it previously.

A sentinel health event for occupation (SHEO) is a disease, disability, or death that is likely to be occupationally related. Its occurrence may serve as a warning signal that materials substitution, engineering control, personal protection, or medical care may be required to reduce the risk of injury or illness among the work force. Sixty-four medical conditions associated with workplace exposures from studies of many different industries have been identified as sentinel health events. Although sentinel health events may indicate an occupational exposure, many may result from non-occupational exposures. Due to this uncertainty, sentinel health events are assessed in two categories:

Definite Sentinel Health Events—Diseases that are unlikely to occur in the absence of an occupational exposure. Asbestosis, a lung disease resulting from exposure to asbestos, is an example.

Possible Sentinel Health Events—Conditions such as lung cancer or carpal tunnel syndrome may or may not be related to occupation. Detailed occupational and nonoccupational information is required to determine the work-relatedness of the illness. For example, lung cancer may result from asbestos exposure or smoking. Carpal tunnel syndrome may result from a job requiring typing or from a hobby such as playing the piano.

Ten definite sentinel health diagnoses were identified among Pantex workers in 2001. Three workers reported five diagnoses of chronic beryllium disease. The five other diagnoses, reported by three workers, were identified as occupational injuries. One worker reported two absences resulting from a torn rotator cuff of the right shoulder. The other two workers each reported one absence for a knee injury and a fractured ankle with nerve damage. The 9 definite SHEO events accounted for 391 calendar days absent from work. Fifteen of 1,544 diagnoses (1 percent) were identified as possible sentinel health events. Ten of the possible sentinel health diagnoses were identified as carpal tunnel syndrome, reported by 8 workers (4 women and 4 men), and resulting in 175 lost calendar days. All these employees were aged 40 and older. Four of the workers were in the Office Management and Administration job category, two were in the Technical Support group, and two were Craft and Repair workers.

During 2001, four deaths occurred among Pantex workers. The two men and one woman were over 50 years old. The other woman was 40-49 years old. Each of the workers was in a different job category. The deaths were due to cancers of the colon and pancreas, respiratory failure, and a motor vehicle accident (Pantex 2001a).

Additionally, female workers at Pantex were included in a National Institute for Occupational Safety and Health funded multisite study of mortality among female nuclear weapons workers. A total of 67,976 women who worked at any of the following 12 Department of Energy sites before January 1, 1980: Oak Ridge (X-10, Y-12, K-25), Los Alamos National Laboratory, the Zia Company, Rocky Flats, Hanford, Mound, Savannah River, Fernald, Pantex, and Linde (closed in 1949).

The study examined the occurrence of deaths among female nuclear weapons workers who worked at any of the 12 sites included in the study. The number of deaths that occurred among these workers was compared with the number of deaths expected to occur based on the mortality experience of the United States female population. The study also attempted to determine if there is a relationship between exposure to ionizing radiation and deaths due to certain diseases. The study report and findings were externally peer reviewed.

For most causes of death, including cancers related to ionizing radiation, fewer female workers died than would be expected based on the U.S. female population. For the entire study population, researchers expected 18,106 deaths from the start of operations through 1993, but found only 13,671 deaths. At all of the sites, the number of deaths were either similar to or lower than expected. These findings are not unusual for worker populations.

A strong healthy worker effect, similar to that observed among male nuclear weapons workers is observed for the entire pooled cohort of female nuclear weapons workers, and for all of the individual subcohorts with the exception of Linde workers. Increased mortality from mental disorders (SMR=147, certain genito-urinary system diseases (SMR =129), as well as symptoms and ill-defined conditions (SMR=163) is found compared with deaths expected based on U.S. death rates. For most causes of death, mortality among female nuclear workers is lower than expected. The healthy worker effect is observed among workers who were badged and among those who were not badged for external radiation exposures. The SMR (observed/expected x 100) for all causes of death combined is 78 for unbadged and 69 for badged workers. Mortality is elevated among both badged and unbadged women for mental disorders. Increased mortality is experienced among unmonitored employees for deaths from symptoms and ill defined conditions, diseases of the genito-urinary system and for homicide. Among badged workers, deaths from ill-defined conditions does not differ from that expected, and is less than expected for diseases of the genito-urinary system and homicide.

The healthy worker effect is also observed in analyses that compare survival time among badged and unbadged workers. For instance, when we assess whether the hazard differs among workers who were issued a radiation badge compared with workers who were not issued a badge, an increased relative risk estimate is observed for all causes of death among women who were not monitored (RR=1.25). This relative risk estimate was slightly lower for deaths from all cancers (RR=1.17). The relative risk for unbadged women who were not monitored is also elevated for lung cancer deaths (RR=1.49).

For the entire pooled cohort, the relative risk of death from leukemia increases with increasing cumulative dose of external radiation (relative risk [RR]/rem = 1.13, 95 percent; CI=1.02- 1.25). Suggestive increases are observed for all cancers (RR/rem = 1.03, 95 percent; CI=0.99- 1.06), breast cancer (RR/rem = 1.05, 95 percent; CI=0.99-1.12), and for hematologic cancers (RR/rem = 1.08, 95 percent; CI=0.99-1.17) (Wilkinson et al. 2000).

B.3.5 Savannah River Site

SRS, established in 1953 in Aiken, South Carolina, produces plutonium, tritium, and other nuclear materials. There are reports that millions of curies of tritium have been released over the years both in plant exhaust plumes and in surface and groundwater streams (DOE 1996c).

Surrounding Communities

In 1984, Sauer and Associates examined mortality rates in Georgia and South Carolina by distance from the Savannah River Plant (now known as SRS) (DOE 1996c). Rates for areas near the plant were compared with U.S. rates and with rates for counties located more than 80 km (50 mi) away. Breast cancer, respiratory cancer, leukemia, thyroid cancer, bone cancer, malignant melanoma of the skin, nonrespiratory cancer, congenital anomalies or birth defects, early infancy death rates, stroke, or cardiovascular disease in the populations living within 80 km (50 mi) of the Plant did not show any excess risk compared with the reference populations.

State Health Agreement Program

Under the State Health Agreement Program managed by DOE's Office of Epidemiologic Studies, a grant was awarded to the Medical University of South Carolina in 1991 to develop the Savannah River Region Health Information System. The purpose of the Savannah River Region Health Information System database was to assess the health of populations surrounding SRS by tracking cancer rates and birth defects rates in the area. Information from the registry is available to public and private health care providers for use in evaluating cancer control efforts. A steering committee provides advice to the Savannah River Region Health Information System and communicates public concerns to the System. It consists of 12 community members and persons with technical expertise representing South Carolina and Georgia. The meetings are open to the public.

Workers

A descriptive mortality study was conducted that included 9,860 white male workers who had been employed at least 90 days at the Savannah River Plant between 1952 and the end of 1974 (DOE 1996c). Vital status was followed through the end of 1980 and mortality was compared with the U.S. population. SMRs were computed separately for hourly and salaried employees. For hourly employees, nonstatistically significant increases were seen for cancer of the rectum (SMR: 1.09, 5 observed), cancer of the pancreas (SMR: 1.08, 10 observed), leukemia and aleukemia (SMR: 1.63, 13 observed), other lymphatic tissue (SMR: 1.06, 5 observed), benign neoplasms (SMR: 1.33, 4 observed), and motor vehicle accidents (SMR: 1.10, 63 observed). Salaried employees exhibited nonstatistically significant increases in cancer of the liver (SMR: 1.84, 3 observed), cancer of the prostate (SMR: 1.35, 5 observed), cancer of the bladder (SMR: 1.87, 4 observed), brain cancer (SMR: 1.06, 4 observed), leukemia and aleukemia (SMR: 1.05, 4 observed), and other lymphatic tissue (SMR: 1.23, 3 observed). No trends between increasing duration of employment and SMRs were observed. A statistically significant excess of leukemia deaths was observed for hourly workers employed at least 5, but less than 15 years (SMR: 2.75, 6 observed). Review of the plant records and job duties of the workers who died from leukemia indicated that two of the cases had potential routine exposure to solvents, four had potential occasional exposure to solvents, and one had potential for minimal exposure. Benzene, a known carcinogen, was reportedly not used at the plant.

Epidemiologic Studies

DOE's Office of Epidemiologic Studies has implemented an Epidemiologic Surveillance Program at SRS to monitor the health of current workers. This program evaluates the occurrence of illness and injury in the workforce on a continuing basis, and the results will be issued in annual reports. The implementation of this program facilitates an ongoing assessment of the health and safety of the SRS workforce and will help identify emerging health issues.

Epidemiologic Surveillance has been conducted at SRS since 1994, and as a pilot project from 1992. The most current available annual report provides a summary of epidemiologic surveillance data collected from SRS from January 1, 2000, through December 31, 2000. The data were collected and submitted to the Epidemiologic Surveillance Data Center located at Oak Ridge Institute for Science and Education, where quality control procedures and preliminary data analyses were carried out. The analyses were interpreted and the final report prepared by the DOE Office of Health Programs. In addition, many factors can affect the completeness and accuracy of health information reported at the sites, thereby affecting the observed patterns of illness and injury.

Currently operational at a number of DOE sites, including production sites and research and development laboratories, epidemiologic surveillance makes use of routinely collected health data including descriptions of illness resulting in absences lasting 5 or more consecutive workdays, disabilities, and Occupational Safety and Health Administration (OSHA)-recordable injuries and illnesses abstracted from the OSHA 200 log. These health event data, coupled with demographic data about the active workforce at the participating sites, are analyzed to evaluate whether particular occupational groups are at increased risk of disease or injury when compared with other workers at a site. As the program continues and data become available for an extended period of time, trend analysis will become an increasingly important part of the evaluation of worker health. Monitoring for changes in the health of the workforce provides both a baseline determination of the illness and injury experience of workers and a tool for monitoring the effects of changes made to improve the safety and health of workers. Noteworthy changes in the health of the workforce may indicate areas in need of more detailed study or increased health and safety measures to ensure adequate protection for workers.

Epidemiologic surveillance monitors all illnesses and injuries among active workers because it is not always possible to determine which health effects are due to occupational exposures and which are due to other causes. Most illness and injury diagnoses were reported to the occupational medicine clinic by workers who required return-to-work clearances. An absence due to illness or injury may involve more than one diagnosis, and epidemiologic surveillance includes all reported diagnoses. In addition, the OSHA 200 Log provides information on recorded occupational injuries and illnesses whether or not they involve absences. The report organizes illness and injury categories based on a standard reference, ICD-9-CM. This reference is used to classify health events for statistical purposes.

Cancer rates presented in this report are based on reported absences during the year. A worker may experience several periods of absence from one cancer diagnosis due to medical complications or treatment regimens. The likelihood that an individual in the United States develops cancer increases with age. SRS data reflect this observation, with higher rates noted among men and women aged 50 or older. Forty-two 5-day absences related to cancer were reported, 24 diagnoses among 19 men and 18 diagnoses among 15 women. One woman who reported cancer in 2000 reported the same cancer in 1998. No apparent relationship was noted between any specific type of cancer and a particular job category.

No consistent relationship between injuries (including non-occupational injuries) and age was seen among men or women. The highest injury rates were among women in the Nuclear Specialties/Power Operator group and among men in the Technical Support group. Compared with other job categories, Technical Support workers were 40 percent more likely to report an injury. These workers had the same increased risk of injury in 1999.

A SHEO is a disease, disability, or death that is likely to be occupationally related. Its occurrence may serve as a warning signal that materials substitution, engineering control, personal protection, or medical care may be required to reduce the risk of injury or illness among the work force. Sixty-four medical conditions associated with workplace exposures from studies of many different industries have been identified as sentinel health events. Although sentinel health events may indicate an occupational exposure, many may result from non-occupational exposures. Due to this uncertainty, sentinel health events are assessed in two categories:

Definite Sentinel Health Events—Diseases that are an unlikely to occur in the absence of an occupational exposure. Asbestosis, a lung disease resulting from exposure to asbestos, is an example.

Possible Sentinel Health Events—Conditions such as lung cancer or carpal tunnel syndrome may or may not be related to occupation. Detailed occupational and non-occupational information is required to determine the work-relatedness of the illness. For example, lung cancer may result from asbestos exposure or smoking. Carpal tunnel syndrome may result from a job requiring typing or from a hobby such as playing the piano.

Twelve definite sentinel health diagnoses reported by four men and two women were identified in 2000. Diagnoses included three sprains and strains (shoulder and upper arm and neck), two open wounds (head and finger), two fainting episodes, and one each for back disorder, bruise of the chest wall, inguinal hernia, seizure disorder, and genito-urinary condition. The causes of these events included falls, overexertion and strenuous movements, being struck by an object, and being cut by a powered hand tool. Twenty-seven of 3,361 (1 percent) diagnoses were identified as possible sentinel health events. Twenty of the 27 diagnoses were carpal tunnel syndrome, reported by 19 workers and resulting in 366 lost calendar days. Ten of the workers reporting carpal tunnel syndrome worked in the Technical Support group. All the workers with this diagnosis were aged 40 or older.

Sixteen deaths occurred among SRS workers in 2000. The causes of death included five cancers (lung, stomach, breast, brain, and multiple myeloma); three injuries (one aircraft accident, one motor vehicle accident, and one self-inflicted gunshot wound); two heart attacks; and one each for heart/circulatory disorder, brain damage, viral infection, psychological disorder, and digestive (liver) condition. The cause of one death was not known. The variety of causes of death did not indicate a pattern among these workers (SRS 2000).

Additionally, female workers at SRS were included in a National Institute for Occupational Safety and Health funded multisite study of mortality among female nuclear weapons workers. A total of 67,976 women who worked at any of the following 12 DOE sites before January 1, 1980: Oak Ridge (X-10, Y-12, K-25), LANL, the Zia Company, Rocky Flats, Hanford, Mound, SRS, Fernald, Pantex, and Linde (closed in 1949).

The study examined the occurrence of deaths among female nuclear weapons workers who worked at any of the 12 sites included in the study. The number of deaths that occurred among these workers was compared with the number of deaths expected to occur based on the mortality experience of the United States female population. The study also attempted to determine if there is a relationship between exposure to ionizing radiation and deaths due to certain diseases. The study report and findings were externally peer reviewed.

For most causes of death, including cancers related to ionizing radiation, fewer female workers died than would be expected based on the U.S. female population. For the entire study population, researchers expected 18,106 deaths from the start of operations through 1993, but found only 13,671 deaths. At all of the sites, the number of deaths were either similar to or lower than expected. These findings are not unusual for worker populations.

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For the entire pooled cohort, the relative risk of death from leukemia increases with increasing cumulative dose of external radiation (RR/rem = 1.13, 95 percent; CI=1.02- 1.25). Suggestive increases are observed for all cancers (RR/rem = 1.03, 95 percent; CI=0.99- 1.06), breast cancer (RR/rem = 1.05, 95 percent; CI=0.99-1.12), and for hematologic cancers (RR/rem = 1.08, 95 percent; CI=0.99-1.17). Among the individual subcohorts, increased relative risks from all cancers and from radiation sensitive cancers combined are observed for female workers at the SRS (Wilkinson et al. 2000).

Memorandum of Understanding

DOE entered into a Memorandum of Understanding with the DHHS to conduct health studies at DOE sites. The Centers for Disease Control and Prevention's National Center for Environmental Health is responsible for dose reconstruction studies and the National Institute for Occupational Safety and Health is responsible for worker studies. These activities are funded by DOE.

A study of mortality among SRS workers employed from 1952-1974 to examine whether risks of death due to selected causes may be related to occupational exposures at SRS is being conducted by the National Institute for Occupational Safety and Health. SRS is also included in several multi-site studies managed by the institute. The first study is to assess the potential association between paternal work-related exposure to ionizing radiation and the risk of leukemia in offspring of exposed male workers. The second study is to examine causes of death among female workers at nuclear weapons facilities to develop risk estimates based on exposures to external and internal ionizing radiation and to hazardous chemicals. A third multisite project is a case-control study of multiple myeloma, a type of blood cell cancer.

A dose reconstruction project around SRS is being conducted by the National Center for Environmental Health to determine the type and amount of contaminants to which people living around the site may have been exposed, to identify exposure pathways of concern, and to quantify the doses people may have received as a result of SRS operations. The study will attempt to determine if the health of people who lived near the Site was affected by past releases of chemicals and radioactive materials from the Site. The study is divided into several stages, which are completed in a phased approach:

- Review historical records (Phase I)
- Select key materials to be evaluated further (Phase I)
- Reconstruct historical releases of key radioactive materials and chemicals (Phase II)
- Develop detailed methods for calculating environmental concentrations
- Estimate doses and risks from exposure to contaminants in the environment.

The study's release estimates are snapshots of what was studied during Phase II of this project. During this Phase II study, details on reactor, reprocessing canyon, and tritium production were located, which will be used in future phases of the study to fill data gaps. Uncertainties in release estimates are also reported, which had not previously been calculated. Some general statements can be made about what has been found. One objective of the Phase II study was to find out if there was enough information in the SRS records to make estimates about the key materials released to the environment. For the key radioactive materials, the answer to this question is yes. The available information for radioactive materials is adequate to develop estimates of dose to individuals living offsite during past SRS operations. However, for the key chemicals, information before the 1980s is very sparse. Rough estimates of chemical releases from SRS operations have been made, and it may be feasible to develop general ranges of chemical risk estimates for offsite residents living near the Site in the past. The Center for Disease Control will carefully evaluate all of this information to carry out Phase III of the study. Another finding of the study is that there are some differences between the estimates of releases reported for this study and those reported by the Site. For the important radioactive materials, these differences are not large in most cases. However, the release estimates to air for iodine-131 reported for this study correct for a measurement problem found in the early records, and they are larger than the SRS-reported values. For similar reasons, plutonium release values to air reported for this study are about 4 times higher than reported SRS numbers during certain time periods. At this time a draft report of Phase II activities has been produced. Dose reconstruction activities based on the site release determinations have not been completed (SRS 1999).

B.3.6 Carlsbad Site

Waste Isolation Pilot Plant (WIPP) received its first shipment of waste on March 26, 1999. Epidemiological reports related to DOE activities are primarily sponsored or conducted in conjunction with NIOSH-CDC and/or DOE-ES&H Health Programs. Since WIPP operations began in 1999, insufficient time has elapsed to generate data appropriate for an epidemiological evaluation. To date, neither NIOSH nor DOE-ES&H Health Programs have issued epidemiological reports for the Carlsbad Site. However, there are two independent DOE-funded research organizations that are currently monitoring the WIPP site from an environmental and epidemiological perspective. Brief descriptions of each organization and their research follow.

Carlsbad Environmental Monitoring & Research Center

The Carlsbad Environmental Monitoring & Research Center (CEMRC) was created in 1991, as a division of the Waste-Management Education & Research Consortium (WERC), in the College of Engineering at New Mexico State University (NMSU). The CEMRC was established with a grant entitled "Carlsbad Environmental Monitoring and Research Program" (CEMRP) from DOE to NMSU (CEMRC 2003).

The primary goals of the CEMRP are to establish a permanent center to anticipate and respond to emerging health and environmental needs, and to develop and implement an independent health and environmental monitoring program in the vicinity of the WIPP and make the results easily accessible to all interested parties (CEMRC 2003).

The CEMRC is monitoring the local residents and studying the environment through a project entitled the "WIPP Environmental Monitoring Project" which includes monitoring of air, soil, surface water, sediments, drinking water, plants, animals, and the human population (CEMRC 2003).

Additionally, the CEMRC, as part of its internal dosimetry program, is conducting an in vivo radiobioassay research project entitled “Lie Down and Be Counted.” The “Lie Down and Be Counted”project serves as a component of the WIPP EM that directly addresses the general concern about personal exposure to contaminants shared by residents who live near many DOE sites. The objective of the research is to characterize and monitor for internally deposited radionuclides in the general population living around the WIPP. The sampling design included solicitation of volunteers from all segments of the community, with sample sizes sufficient to meet or exceed a 15 percent range margin of error for comparisons between major population ethnicity and gender categories as identified in the 1990 census. The minimum sample size threshold was achieved for the major categories early in 1998, and is as low as 8 percent margin of error range for some categories. The data collected prior to the opening of the WIPP facility (March 26, 1999) serve as a baseline for comparisons with periodic follow-up measurements that are slated to continue throughout the 35-year operational phase of the WIPP. Participants in the project are monitored every 2 years (CEMRC 2003).

The Table B.3.6–1 summarizes the number of lung and whole body counts performed at CEMRC since the in vivo bioassay facility was commissioned in August 1997 (CEMRC 2003).

Table B.3.6–1. Lung and Whole Body Count Totals as of June 1, 2001

Total number of individuals who have participated in the project	546
Total number of counts of LD&BC participants (includes recounts of some individuals)	677
Total number of lung and whole body counts performed at the Center since July 1997	1832

Source: CEMRC 2003.

Results

The most current results, published June 1, 2001, indicate that operational monitoring results for all radionuclides are consistent with the baseline results. Based on these data, there is no evidence of a change in the frequency of detection of internally deposited radionuclides for citizens living within the vicinity of WIPP, since WIPP began receipt of radioactive waste (CEMRC 2003).

Environmental Evaluation Group of New Mexico

The Environmental Evaluation Group of New Mexico (EEG) is an interdisciplinary group of scientists and engineers that provides independent technical evaluation of the WIPP to ensure the protection of public health and safety, and the environment of New Mexico. The EEG was established in 1978 through a contract between the State of New Mexico and DOE (EEG 2003). A 1981 Agreement for Consultation and Cooperation (C&C) between DOE and the State of New Mexico and the *WIPP Land Withdrawal Act*, PL 102-579, also established EEG as an oversight organization for the WIPP Project on behalf of the State of New Mexico. Then, in 1989, Public Law 100-456, the *National Defense Authorization Act*, Fiscal Year (FY) 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original DOE contract. Finally, the *National Defense Authorization Act* for FY 1994, Public Law 103-

160, and the *National Defense Authorization Act* for FY 2000, Public Law 106-65, continued the authorization for an additional five years (EEG 2003).

EEG began its Environmental Monitoring Program in 1984 under the terms of the July 1981 C&C Agreement and a December 1982 Supplemental Stipulated Agreement. Environmental data collected by EEG before the opening of the WIPP has provided a baseline of environmental radionuclide background concentrations. Now that the facility is receiving waste, analytical results obtained from the effluent air and effluent water are being used to evaluate WIPP's regulatory compliance. EEG's Environmental Monitoring Program independently measures radioactivity in the air, water, and soil at the WIPP and in surrounding communities. Samples are analyzed for Americium-241, Cesium-137, Plutonium-238, Plutonium-239+240, and Strontium-90 (EEG 2003).

These particular radionuclides account for more than 98 percent of the potential public radiation dose from WIPP operations. In the event of WIPP-related transportation accidents or releases from WIPP facility operations, contamination of communities surrounding the WIPP facility can be assessed (EEG 2003).

Results

The most current results of EEG's Environmental Monitoring Program indicate that operations at the WIPP site during 2001 did not result in detectable releases of radionuclides to the environment. There "was no increase when compared with 1993-1998 baseline measurements and operational measurements taken during 2001" (EEG 2003).

B.4 DESCRIPTION OF THE CAP-88 COMPUTER CODE

Emission monitoring and compliance procedures for DOE facilities (40 CFR 61.93 [a]) require the use of CAP-88 (which stands for *Clean Air Act* Assessment Package-1988) or AIRDOS-PC computer models, or other approved procedures, to calculate effective dose equivalents to members of the public. The CAP-88 computer model is a set of computer programs, databases, and associated utility programs for estimation of dose and risk from radionuclide emissions to air.

CAP88-PC provides the CAP-88 methodology for assessments of both collective populations and maximally exposed individuals. CAP88-PC differs from the dose assessment software AIRDOS-PC in that it estimates risk as well as dose, offers a wider selection of radionuclide and meteorological data, provides the capability for collective population assessments, and allows users greater freedom to alter values of environmental transport variables. CAP88-PC version 1.0 was approved for demonstrating compliance with 40 CFR 61.93 (a) in February 1992.

B.4.1 Model Summary

CAP88-PC uses a modified Gaussian plume equation to estimate the average dispersion of radionuclides released from up to six emitting sources. The sources may be either elevated stacks, such as a smokestack, or uniform area sources, such as a pile of uranium mill tailings. Plume rise can be calculated assuming either a momentum or buoyant-driven plume.

Assessments are done for a circular grid of distances and directions for a radius of up to 80 km (50 mi) around the facility. The Gaussian plume model produces results that agree with experimental data as well as any model, is fairly easy to work with, and is consistent with the random nature of turbulence.

Sample population files are supplied with CAP88-PC, which the user may modify to reflect their own population distributions. When performing population dose assessments, CAP88-PC uses the distances in the population array to determine the sector midpoint distances where the code calculates concentrations. CAP88-PC only uses circular grids; square grids are not an option.

Agricultural arrays of milk cattle, beef cattle, and agricultural crop area are generated automatically, requiring the user to supply only the state name or agricultural productivity values. When a population assessment is performed, the arrays are generated to match the distances used in the population arrays supplied to the code, and use state-specific or user-supplied agricultural productivity values. Users are given the option to override the default agricultural productivity values by entering the data directly on the Agricultural Data tab form.

Organs and weighting factors follow the ICRP 26/30 Effective Dose Equivalent calculations, which eliminates flexibility on specifying organs and weighting factors. The calculation of deposition velocity and the default scavenging coefficient is also modified to incorporate current EPA policy. Deposition velocity is set to 3.5×10^{-2} meters per second (m/s) for iodine, 1.8×10^{-3} m/s for particulates, and 0.0 m/s for gases. The default scavenging coefficient is calculated as a function of annual precipitation.

Seven organs are valid for the Effective Dose Equivalent as follows: gonads: 25 percent; breast: 15 percent; red bone marrow: 12 percent; lungs: 12 percent; thyroid: 3 percent; lung, thyroid, bone surfaces: 3 percent; and remainder: 30 percent.

B.4.2 Validation

The CAP88-PC programs represent one of the best available validated codes for the purpose of making comprehensive dose and risk assessments. The Gaussian plume model used in CAP88-PC to estimate dispersion of radionuclides in air is one of the most commonly used models in government guidebooks. It produces results that agree with experimental data as well as any model, is fairly easy to work with, and is consistent with the random nature of turbulence.

The EPA Office of Radiation and Indoor Air has made comparisons between the predictions of annual-average ground-level concentration to actual environmental measurements, and found very good agreement. In the paper "Comparison of AIRDOS-EPA Prediction of Ground-Level Airborne Radionuclide Concentrations to Measured Values," environmental monitoring data at five DOE sites were compared to AIRDOS-EPA predictions. EPA concluded that as often as not, AIRDOS-EPA predictions are within a factor of 2 of actual concentrations.